Traditional water structures in villages support amphibian populations within a protected landscape

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Abstract

Amphibians are among the most globally threatened vertebrates, with habitat loss and degradation being the primary drivers of their decline. While natural wetlands are essential for amphibian survival, artificial habitats can also play a significant role as refuges, especially in human-altered landscapes. This study examines the role of artificial waterbodies in supporting amphibian populations within villages and human-disturbed areas of Peneda-Gerês National Park (PNPG) in northern Portugal, a unique protected area recognized for its rich natural and cultural heritage. We conducted surveys across 162 natural (ponds, streams, stream pockets, caves) and artificial (tanks, drains, fountains, cave-like structures), waterbodies, to assess species richness, abundance, and breeding activity in human-altered landscapes within PNG. A total of ten amphibian species were observed, with natural waterbodies showing higher species richness and occupancy rates. The Iberian frog (*Rana iberica*) was the most abundant species, found primarily in natural habitats, where it bred exclusively. Although the fire salamander (*Salamandra salamandra*) was also most common in natural waterbodies, it bred across a wide range of both natural and artificial waterbodies. In contrast, the endemic Bosca's newt (*Lissotriton boscai*) and the marbled newt (*Triturus marmoratus*) were more prevalent in artificial waterbodies, particularly in historic water tanks. These water tanks, traditionally used for laundry and water storage in local villages, were crucial for these amphibians, with approximately two-thirds occupied and over a quarter serving as breeding sites for four different species—supporting more species than all the natural waterbodies combined. These findings emphasize the need to integrate the conservation of both natural and artificial aquatic habitats to sustain amphibian biodiversity, particularly in human-altered landscapes like PNPG. As climate change diminishes natural breeding sites, artificial waterbodies can offer crucial refuges that complement natural habitats, playing a vital role in protecting both biodiversity and the region's cultural heritage.

Key Words: Amphibians; Artificial habitats, Bosca’s newt (Lissotriton boscai); Cultural Heritage; Drainage Systems (Open Channels and Drains); Fire salamander (Salamandra salamandra); Iberia; Marbled newt (Triturus marmoratus); Portugal; Peneda-Gerês National Park; Rana iberica (Iberian frog); Fire salamander (Salamandra salamandra); Water Tanks

Introduction

Amphibians are the most globally threatened vertebrate group, with more than 40% of all species at risk of extinction, primarily driven by habitat loss and degradation, emerging infectious diseases, and the effects of climate change (Stuart et al. 2004, Luedtke et al. 2023). Habitat loss in particular poses the most critical threat impacting 93% of endangered amphibian species (Luedtke et al. 2023). The loss and alteration of both aquatic breeding grounds and terrestrial habitats plays a significant role by disrupting the complex biphasic life cycles typical of most amphibians (Cushman 2006, Becker et al. 2007). Their highly permeable skin also makes them particularly vulnerable to environmental changes, making them sensitive to fluctuations in moisture, temperature, and pollutant exposure in both aquatic and terrestrial environments (Alford and Richards 1999). However, the impact of habitat changes on amphibian populations varies across species and habitats (Hamer and McDonnell 2008, Pyron 2018, Valdez et al. 2021). While pristine wetlands and forests provide ideal conditions, some artificial habitats can offer supplemental refuge when natural areas are lost or degraded.

Recent studies show that roughly one-third of the world's amphibian species use artificial habitats to some extent, even occupying heavily altered environments (Warren and Büttner 2008, Valdez et al. 2015, 2021). Although not a substitute for natural habitats, constructed waterbodies like drainage ditches, rice paddies, agricultural ponds, and wastewater treatment ponds can provide vital alternative aquatic breeding grounds, helping to support and sustain populations of threatened amphibian species when natural habitats become scarce or degraded (Knutson et al. 2004, Brand and Snodgrass 2010, Valdez et al. 2015, Boissinot et al. 2019, Caballero-Díaz et al. 2020, Yu et al. 2022, Conan et al. 2023, Romano et al. 2023). Additionally, terrestrial habitats like plantations, pastures, gardens, and urban greenspaces can serve as habitats when forests become fragmented or degraded (Hartel 2004, Manenti et al. 2013, Holzer 2014, Valdez et al. 2021, Yu et al. 2022). Nevertheless, while some artificial habitats can support certain amphibian species, many others are less beneficial due to limitations such as altered hydrology, ecological traps, pollution, and invasive species, which can lead to lower survival rates and reduced biodiversity compared to natural areas (Knutson et al. 2004, Hamer and McDonnell 2008, Gordon et al. 2009, Price et al. 2011, Cordier et al. 2021, Băncilă et al. 2023). Determining whether individual artificial habitats support or threaten particular amphibian populations is key to evaluating their long-term conservation value, especially in regions with a legacy of extensive anthropogenic landscape alteration.

In Europe, for example, approximately 80% of landscapes have been extensively transformed over the past centuries due to agricultural intensification, urbanization, and infrastructure expansion (Pedroli and Meiner 2017, European Environment Agency 2023). These changes have led to the loss of over 50% of wetlands in many European countries due to the draining of floodplains and peatlands for agriculture and urbanization (Fluet-Chouinard et al. 2023). Meanwhile, since the 1990s, the expansion of artificial land has accelerated more than any other land cover type, driven by ongoing urbanization and infrastructure construction (Pedroli and Meiner 2017). Nevertheless, some artificial habitats such as stormwater ponds, highway drainage systems, and fish farms have been found to partly mitigate the impact of natural habitat loss for some species in certain areas (Kloskowski 2010, Le Viol et al. 2012, Conan et al. 2023).

In the drought-prone Mediterranean climate of the Iberian Peninsula, encompassing Spain and Portugal, artificial water bodies may be especially valuable for amphibian species. Evidence suggests that structures such as irrigation canals, farm ponds, water tanks, ditches, and abandoned quarries can serve as habitats, providing critical network connectivity for dispersal and additional breeding habitats for many amphibian populations in this water-scarce and heavily altered region (Garcia-Gonzalez and Garcia-Vazquez 2011, Ferreira and Beja 2013, Galvez et al. 2018, Caballero-Díaz et al. 2020, 2022, Gutiérrez-Rodríguez et al. 2023). Understanding amphibian use of artificial habitats is vital to support populations now reliant on these man-made habitats, especially in the Iberian region, which contains the highest concentration of endemic and threatened amphibian species in Europe (Temple and Cox 2009, Luedtke et al. 2023).

While many studies have explored the importance of specific artificial habitats for amphibians, there appears to be a lack of studies on the use of these habitats within protected areas. Peneda-Gerês National Park (PNPG) in northern Portugal, the oldest protected area and the only national park in the country, offers an ideal setting to investigate amphibian use of artificial habitats within a protected area (Soares et al. 2005). Established in 1971 and part of the "Natura 2000" network of European priority conservation areas, PNPG is situated at the crossroads of Euro-Siberian and Mediterranean zones, creating a unique climatic transition from Atlantic to Mediterranean conditions (Soares and Brito 2007). This blending of two distinct bioclimatic regions enables the park to serve as a biodiversity hotspot, hosting thirteen amphibian species and four Iberian endemics that thrive in its pristine montane streams, rivers, and ponds (Soares et al. 2005). However, the park also encompasses traditional mountain villages, home to centuries-old artificial waterbodies like historic stone fountains, communal laundry and water tanks, and drainage channels that were once vital to traditional village life (Soares and Brito 2007, Cabral et al. 2017, Simões et al. 2019, Martins 2022). These historically significant structures not only serve as cultural landmarks but also present a valuable opportunity to explore their potential as biodiversity refuges for amphibians within this unique protected area. Understanding the role of artificial habitats in PNPG is crucial for managing and protecting amphibian populations within this ecologically rich landscape shaped by natural and cultural elements.

In this study, we investigate the role of artificial waterbodies in supporting amphibian populations within Peneda-Gerês National Park (PNPG), focusing on villages and other human-altered areas within its protected landscape. We compare amphibian species richness, abundance, and breeding activity between artificial waterbodies (tanks, drains, fountains, and cave-like structures) and natural habitats (ponds, streams, stream pockets, and caves). Additionally, we use Principal Component Analysis (PCA) to examine the differences and similarities in habitat characteristics across the various waterbody types. This study aims to understand the ecological significance of artificial waterbodies in supporting amphibian populations within this unique protected area, where natural and cultural heritage intersect.

Methods

Study area

The study was conducted over two survey periods: May 17-21, 2023, and May 6-12, 2024. It covered 11 villages and human-disturbed areas within Peneda-Gerês National Park in northern Portugal, including Alcobaça, Assureira, Barreiro, Castro Laboreiro, Couscadas, Dorna, Lamas de Mouro, Mareco, Pousios, Ribeiro de Beixo, and Ribeiro de Cima. In total, 162 waterbodies were surveyed, consisting of 68 artificial and 94 natural waterbodies (Appendix S1: Figure S1).

Waterbody types

We categorized the various waterbodies into natural and artificial types (Figure 1). For natural habitats, we identified four categories: ponds, streams, stream pockets, and caves. Ponds (Figure 1a) are small natural standing bodies of freshwater, while streams (Figure 1b) are small, shallow, naturally flowing bodies of water typically originating from springs or rainfall. Stream pockets (Figure 1c) are localized areas within deeper and wider stream systems where water flow is more concentrated or pooled. Caves (Figure 1d) refer to naturally formed hollow spaces or chambers within rock formations that contain bodies of water. Within the artificial category, we identified four types of waterbodies: tanks, drains, fountains, and cave-like structures. Tanks (Figure 1e) are artificial containers historically used for storing water, often for laundry or troughs. Drains (Figure 1f) are man-made structures typically located at ground level, such as open drainage channels, designed to redirect excess rainwater and runoff, preventing water accumulation in village streets and agricultural areas. Fountains (Figure 1g) are ornamental features with flowing water situated at higher elevations. Cave-like structures (Figure 1h) are artificial, enclosed spaces that mimic the appearance and environment of natural water-containing caves.

Figure 1. Types of waterbodies surveyed within Peneda-Gerês National Park. Natural waterbodies include (a) ponds, (b) streams, (c) stream pockets, and (d) caves. Artificial waterbodies are represented by (e) tanks, (f) drains, (g) fountains, and (h) cave-like structures.

Survey sampling

Amphibian sampling was conducted through systematic nocturnal surveys typically between 20:30 and 02:00. We searched waterbodies by walking along their perimeters, using visual encounter surveys (VES) to observe amphibians. Additionally, auditory sampling was performed to record species based on calls. Dip-net sweeps in a figure-8 motion were used to collect amphibian larvae and adults for counting and species identification. The presence of larvae was taken as evidence of breeding at the waterbody. We measured environmental variables, including waterbody dimensions, depth, turbidity, temperature, pH, water flow.

Additionally, we estimated the percentage cover of habitat features including rocks, mud, leaf litter, and aquatic vegetation.

Statistical analyses

We used R version 4.2.2 to analyze differences in amphibian occupancy, abundance, and breeding across species, as well as between artificial and natural waterbody types. A Chi-square test of independence was employed to examine the relationship between species, waterbody types, and occupancy status (occupied vs. unoccupied sites). Mean abundance differences across species and waterbody types were assessed using a one-way ANOVA, with post-hoc tests to identify significant pairwise differences. Welch's two-sample t-test was used to compare mean amphibian abundance between artificial and natural habitats. Additionally, Chi-square tests were performed to explore associations between species, waterbody types, and breeding activity.

We conducted a Principal Component Analysis (PCA) using the FactoMineR package in R to explore the relationship between waterbody characteristics. Continuous variables were standardized for comparability, and categorical variables were converted into dummy variables. Rows with missing data were removed to create a clean dataset. After an initial PCA, we applied a contribution threshold of 5% to focus on the most significant variables contributing to the variation in the first two principal components. Variables exceeding this threshold were retained, and the PCA was rerun using the reduced dataset. The results were visualized with the factoextra package, using a gradient color scale to highlight the contribution of each variable and identify the key characteristics differentiating the waterbodies.

Results

Species richness

We found ten amphibian species within our study area, comprising six frog species (Order: Anura) and four salamander species (Order: Urodela). Among the frogs, we recorded the Iberian frog (*Rana iberica*), Perez's frog (*Pelophylax perezi*), Spiny toad (*Bufo spinosus*), Common midwife toad (*Alytes obstetricans*), Natterjack toad (*Epidalea calamita*), and Iberian painted frog (*Discoglossus galganoi*). The salamander species included the Fire salamander (*Salamandra salamandra*) and three newt species within the subfamily Pleurodelinae: Marbled newt (*Triturus marmoratus*) and Bosca's newt (*Lissotriton boscai*), along with the Iberian ribbed newt (*Chioglossa lusitanica*).

Natural waterbodies had the highest species richness, with nine out of the ten amphibian species observed, whereas artificial waterbodies hosted only seven species (Appendix S1: Figure S1). *Discoglossus galganoi*, *Epidalea calamita*, and *Chioglossa lusitanica* were exclusively found in natural habitats, while *Alytes obstetricans* were only observed in artificial water bodies (Appendix S1: Figure S2). However, we also heard the midwife toad's call (*Alytes obstetricans*) in nearby natural habitats, suggesting its presence there despite not being visually confirmed. Amphibian species richness also varied across different waterbody types (Appendix S1: Figure S2). Within natural waterbodies, stream pockets, ponds, and streams each had six species, while caves had four species (Appendix S1: Figure S2). In contrast, drains had the highest richness among artificial and all waterbodies, with seven species, followed closely by tanks with six species (Appendix S1: Figure S2). Artificial caves and fountains were less diverse, containing only two and one species, respectively (Appendix S1: Figure S2).

Species abundance

There were significant differences in mean abundance across different waterbody types and species. ANOVA results indicated significant effects for the different waterbody types ($F = 20.17$, $p = 0.048$), species ($F = 61.40$, $p = 0.0161$), and their interaction ($F = 31.43$, $p = 0.0313$). Although natural waterbodies exhibited a higher mean abundance (4.65) compared to artificial sites (3.32), it was not significant ($t = -1.612$, $df = 124.52$, $p = 0.054$). Nevertheless, this slightly higher abundance observed may be largely attributed to the abundance of *R. iberica*, the most abundant species with 337 individuals observed, representing 61.27% of all amphibians recorded. The vast majority (90.8%) were found in natural waterbodies, particularly in stream pockets, ponds, and streams (Figure 2). *L. boscai* was the second most abundant species (56 individuals) and predominantly found in artificial waterbodies (78.6% of observations), with the highest abundance in tanks (Figure 2). *S. salamandra* was the third most common (55 individuals) and mainly observed in natural habitats (87.3% of observations), especially in stream pockets (Figure 2). *P. perezi* had 43 individuals recorded and was mainly (62.8%) found in natural waterbodies, especially ponds, but also in artificial tanks (Figure 2). *T. marmoratus* had 42 individuals and was mostly observed (71.4% of observations) in artificial sites, particularly in tanks (Figure 2). The remaining species were much less abundant, but *B. spinosus*, and *A. obstetricans* were mostly found in artificial habitats (drains and tanks) while *E. calamita*, *D. galganoi*, *C. lusitanica* were found only in natural habitats (Figure 2).

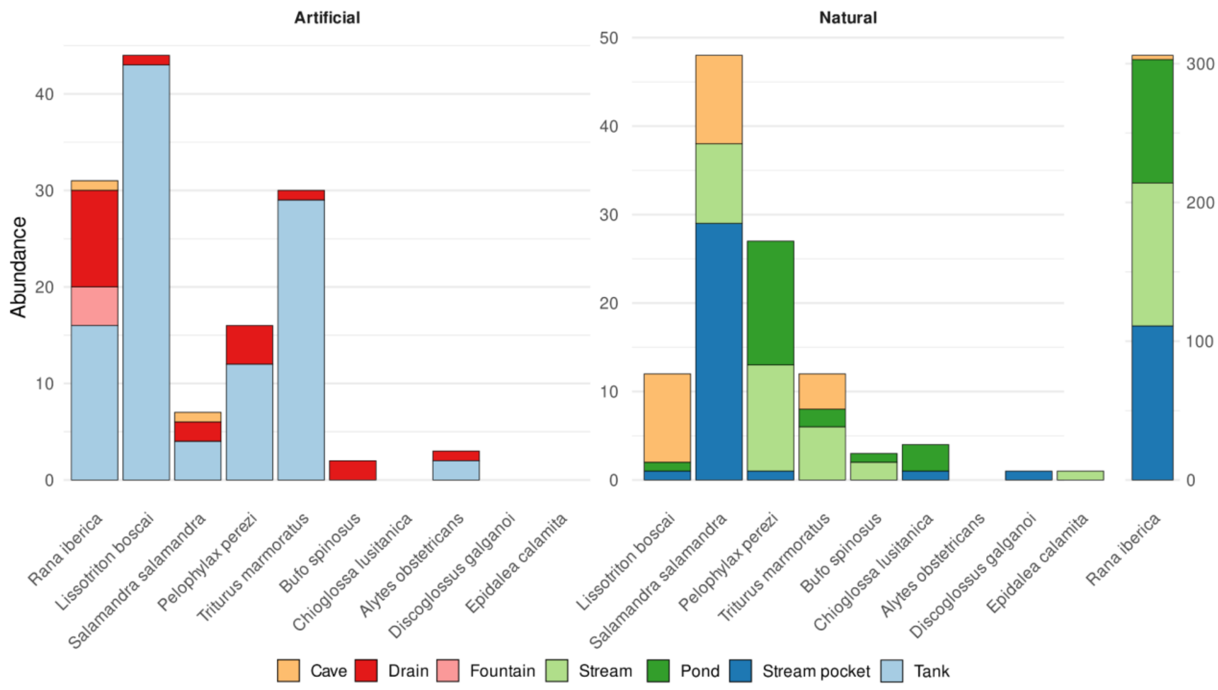

Figure 2. Stacked bar plot showing the abundance of amphibian species observed in different types of artificial and natural waterbodies in Peneda National Park.

Site occupancy

There was a significant difference in occupancy rates between artificial and natural waterbodies, with 35 (51.5%) artificial sites and 72 (76.6%) natural sites occupied with at least one species ($X^2 = 10.015$, df = 1, $p = 0.0016$). Over the two survey periods, all of the different types of natural waterbodies had most (at least 50%) of their sites occupied at least once. In contrast, among artificial waterbodies, only tanks had the majority of their sites occupied across the study area. Additionally, only six artificial (8.82%) and 16 natural (17.02%) waterbodies were occupied in both years.

The occupancy rates for waterbody types reveal significant differences between all the artificial and natural waterbody types (Fisher's Exact Test: $p < 0.001$). Natural waterbodies exhibited generally higher occupancy rates, with stream pockets showing the highest occupancy at 96.6%, followed by streams (69.4%), ponds (64%), and caves (66.7%) (Figure 3a). In contrast, among artificial waterbodies, occupancy was highest in tanks (62.5%), followed by drains (42.9%), fountains (28.6%), and caves (100%), although the latter was based on a single site.

Occupancy also rates differed significantly among species ($X^2 = 357.9$, $p < 0.001$). *R. iberica* was by far the most widespread species found in 78, or nearly half (48.1%) of all waterbodies surveyed, with most occurring in natural waterbodies (60 sites or 63.8% of all natural sites) compared to artificial ones (18 sites or 26.5% of all artificial waterbodies) (Figure 3b). *S. salamandra* was present in 19 sites (11.7% of all waterbodies), predominantly in natural waterbodies (15 sites or 16.0% of all natural sites) (Figure 3b). *T. marmoratus* and *P. perezi* were each found in 8.6% of all waterbodies, with *T. marmoratus* more common in artificial waterbodies (eight sites or 11.8% of artificial waterbodies) and *P. perezi* in natural ones (nine sites, or 9.6% of natural waterbodies) (Figure 3b). *L. boscai* was recorded at eleven waterbodies, mostly in artificial waterbodies (8 sites or 11.8% of artificial waterbodies) (Figure 3b).

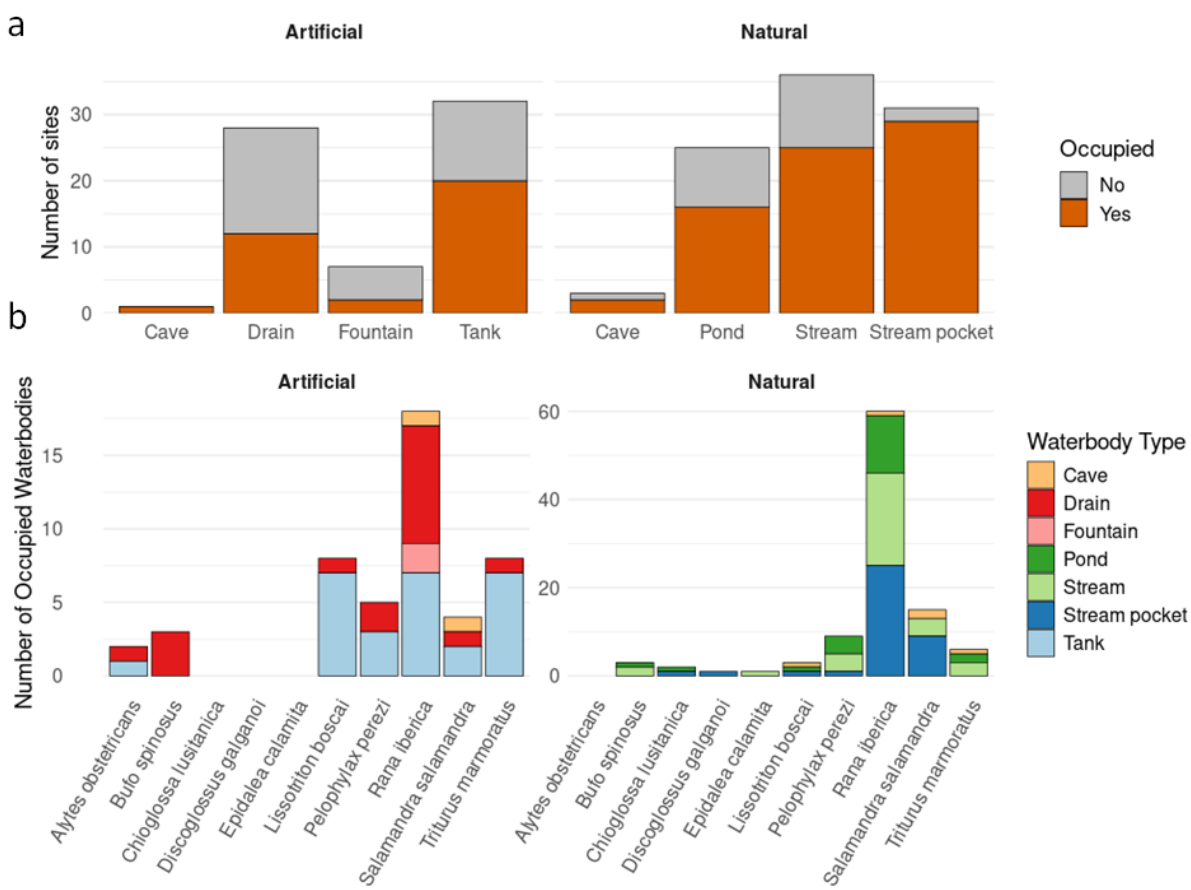

Figure 3: Total number of occupied and unoccupied waterbodies across different artificial and natural types (a) and species-specific occupancy in artificial and natural waterbodies (b) in Peneda-Gerês National Park.

Reproduction

Breeding was observed 38 times across 35 waterbodies or 21.6% of all surveyed waterbodies. Although a higher percentage of breeding was recorded within the natural waterbodies (25.5%) compared to artificial ones (16.2%), this difference was not statistically significant ($X^2 = 1.524$, $p = 0.1085$). However, we found significant variations in breeding patterns across the different waterbody types ($X^2 = 368.8$, $df = 9$, $p < 0.001$) (Figure 4). In artificial habitats, nearly all sites where breeding occurred were tanks, representing 28.1% of all surveyed tanks (Figure 4). For natural habitats, stream pockets were the most common breeding locations (15 waterbodies), with 50% of stream pockets having breeding occurrences (Figure 4). Notably, 75% of all caves, both artificial and natural, showed breeding activity, although the sample size for caves (four) was small (Figure 4). While artificial waterbodies maintained relatively consistent breeding activity across the two breeding seasons (five and six breeding occurrences), natural waterbodies showed a large decrease from 20 breeding to seven in the subsequent season.

Breeding was observed for five of the ten species, with four species breeding in artificial waterbodies and three species in natural waterbodies during the two survey periods (Figure 4). *S. salamandra* exhibited the highest breeding frequency, with a total of eighteen events: four in artificial habitats and 14 in natural ones (Figure 4). This species was found breeding in the widest range of waterbody types, except fountains, where no species were found to breed (Figure 4). *R. iberica* had 15 breeding events, all within natural habitats, specifically in caves, streams, and stream pockets (Figure 4). *L. boscai* had six breeding events, with five occurring in tanks and one in a natural cave (Figure 4). *P. perezi* and *T. marmoratus* each had one breeding event, both occurring in tanks (Figure 4).

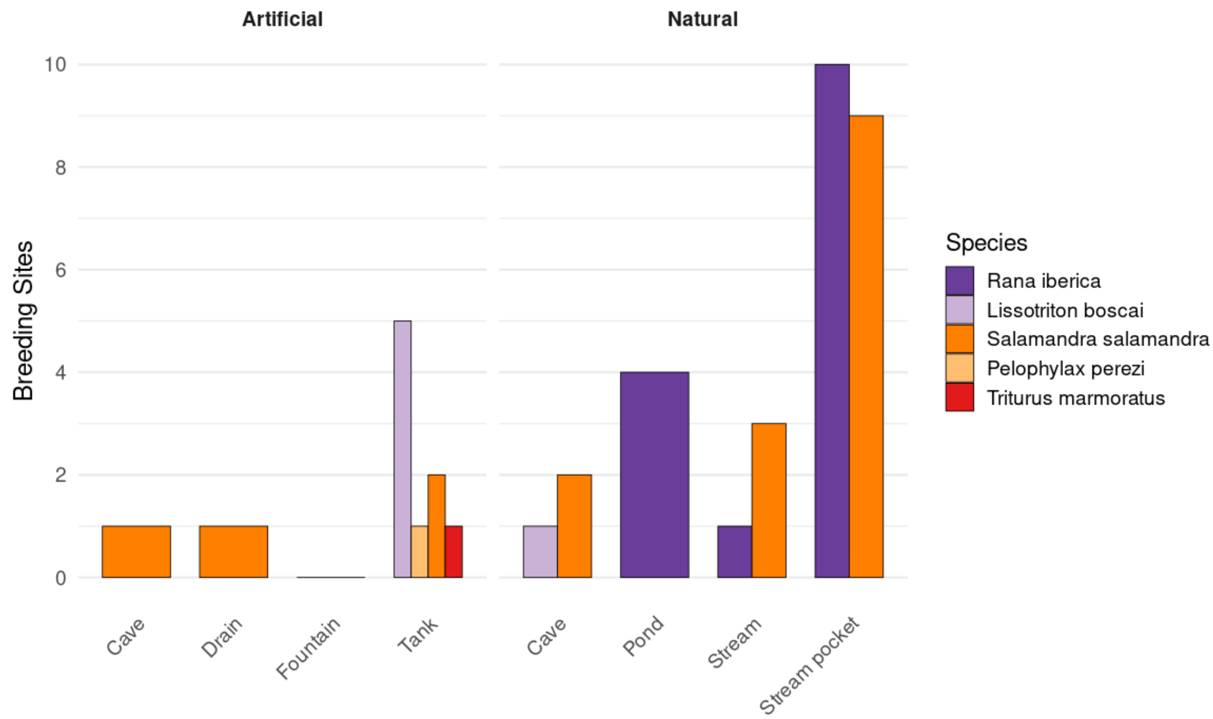

Figure 4: Number of breeding sites for amphibian species across different artificial and natural waterbody types in Peneda National Park.

Waterbodies characteristics

The PCA biplot shows the relationships between key environmental variables, with the first principal component (Dim1) explaining 31.2% and the second principal component (Dim2) accounting for 20.5% of the variance, together capturing 51.7% of the total variation (Figure 5). This analysis highlights clear distinctions between natural and artificial waterbodies, primarily shaped by water flow and habitat characteristics. Natural habitats are located in the upper left of the plot, closely associated with streams and ponds. Streams are linked to medium water flow, indicating their connection to dynamic environments, while ponds are associated with still water flow, reflecting stagnant conditions. Medium water flow and bare rock are positioned between streams and drains, suggesting that drains share similarities with natural flowing water systems.

Although still water flow is positioned between ponds and tanks, indicating a shared characteristic of stagnation due to minimal water movement, tanks are distinctly located far to the right on the biplot. This positioning highlights their association with increased height above ground and greater water depth, highlighting their elevated and man-made nature, which further distinguishes them from natural waterbodies.

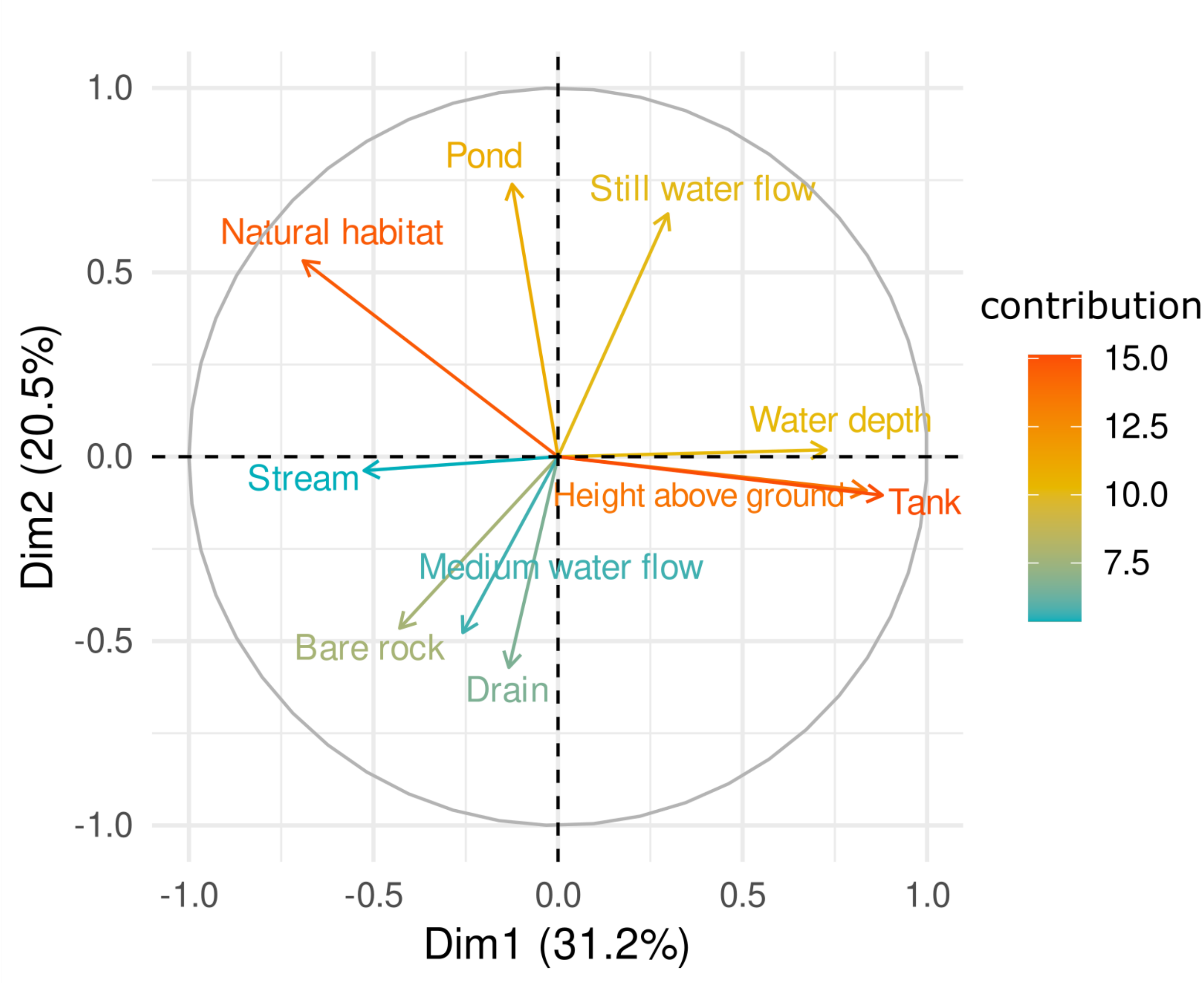

Figure 5. PCA biplot of environmental variables for waterbodies surveyed in Peneda National Park. The plot illustrates the contributions of environmental variables to the first two principal components (Dim1 and Dim2), which explain 31.2% and 20.5% of the variance, respectively. Arrows indicate the direction and strength of each variable's contribution and correlation to the components, with a color gradient showing higher contributions in warmer colors.

Discussion

Our study highlights the critical role that both natural and artificial habitats play in supporting amphibian populations within the protected landscape of Peneda-Gerês National Park (PNPG). These findings demonstrate that while natural waterbodies are critical for amphibians, artificial aquatic features within villages in PNPG, particularly water tanks and drainage channels, can play a crucial role in sustaining local amphibian populations, aligning with previous studies on the importance of these artificial waterbodies in human-disturbed landscapes (Knutson et al. 2004, Mazerolle 2005, Brand and Snodgrass 2010, Valdez et al. 2015, Yu et al. 2022, Caballero-Díaz et al. 2022, Romano et al. 2023). While natural waterbodies exhibited higher overall species richness and occupancy rates, our results show that artificial waterbodies, despite their human-altered nature, can serve as valuable complementary habitats for certain amphibian species. Historical water tanks, in particular, not only supported a comparable diversity of species as natural waterbodies but also showed significant occupancy rates and breeding activity, particularly for species like the endemic *L. boscai* and *T. marmoratus*. This suggests that these man-made water features are not merely supplementary but can play a crucial role in providing essential breeding and refuge sites for these amphibian populations.

In total, we found ten amphibian species during the study, including six of the eight Anura and four of the five Urodela species that occupy the PNPG. *Rana iberica* was by far the most abundant among the observed species, constituting over 60% of all recorded individuals. This species was predominantly found in natural waterbodies, such as stream pockets and natural ponds. *L. boscai* and *S. salamandra* also showed high abundances, with the former being more abundant in artificial habitats, particularly tanks, and the latter more abundant in natural habitats. *T. marmoratus* was most abundant in artificial tanks, while *P. perezi* was notably more abundant in natural ponds but also present in some tanks. These patterns align with previous studies in PNPG, which identified these species as more common and widely distributed in the park (Godinho et al. 1999, Soares et al. 2005). In contrast, *B. spinosus* and *A. obstetricans* were less numerous but more frequently found in artificial environments. Meanwhile, *D. galganoi*, *C. lusitanica*, and *E. calamita* were exclusive to natural habitats but recorded at only one or two sites each, highlighting their small and fragmented distribution within the park (Soares et al. 2005). Although *T. helveticus*, *P. cultripes*, and *H. arborea* were not observed, this was likely due to their scarcity in PNPG and preference for fossorial and arboreal habitats which were not covered in this study (Soares et al. 2005).

We found that natural waterbodies had generally higher occupancy rates, abundance, and breeding activity compared to artificial ones. Specifically, three-quarters of all natural waterbodies were occupied at least once during the study, while half of the artificial sites were occupied. Although slightly more amphibian species were observed breeding in natural habitats, the difference in the total number of breeding events between natural and artificial sites was not statistically significant, indicating that artificial waterbodies play a role in amphibian reproduction. Comparable findings have shown that artificial sites, such as water tanks, ponds, and drainage channels, can provide important breeding habitats for amphibians, especially in landscapes altered by human activity (Brand and Snodgrass 2010, Ferreira and Beja 2013, Caballero-Díaz et al. 2020, 2022, Romano et al. 2023). Among the natural habitats, stream pockets were particularly crucial, with nearly all sites occupied at least once and serving as vital refuges and breeding sites for species such as *S. salamandra* and *R. iberica*. However, although a slightly greater number of amphibian species were observed breeding in natural habitats, the difference in the number of breeding events between natural and artificial sites was not statistically significant. We found that *R. iberica* bred exclusively in natural waterbodies, while *S. salamandra* highlighted its adaptability to different habitats by breeding in every type of natural and artificial habitats, except fountains where no breeding occurred by any species. The absence of breeding activity in fountains may be attributed to factors such as high water flow, lack of suitable substrates, chemical cleaning, or frequent human disturbance, making them less favorable for amphibian reproduction. While ponds and caves also supported some breeding events they were much less commonly used in general.

Artificial waterbodies, despite lower overall occupancy rates, played a critical role in supporting amphibian diversity and reproduction. Tanks were particularly important, with two-thirds being occupied at least once during the two seasons, the highest occupancy rate among the artificial waterbodies. These historical tanks supported breeding activity for four out of the five breeding species recorded (*L. boscai*, *S. salamandra*, *T. marmoratus*, and *P. perezi*), except for *R. iberica*, which only bred in natural habitats. This diversity was greater than all natural waterbodies combined, which supported only the three most common species (*R. iberica*, *S. salamandra*, and *L. boscai*). Notably, *T. marmoratus* and *P. perezi* were found breeding exclusively in tanks, albeit only once each. These results demonstrate how these historical artificial waterbodies complement the park's natural waterbodies by providing vital refuges and additional breeding sites for a diverse range of amphibian species. Typically elevated and fish-free, such tanks provide stable hydrological conditions and protection from predators, significantly improving breeding success and larval survival (Garcia-Gonzalez and Garcia-Vazquez 2011, Ferreira and Beja 2013, Cabral et al. 2017, Arillo et al. 2022, Gould et al. 2024). Additionally, consistent with previous studies (Mazerolle 2005, Yu et al. 2022), drainage channels were also found to be an important artificial habitat, with nearly 40% of them occupied at least once and hosting the highest number of species among all waterbody types.

Although this study offers valuable insights into the role of human-modified waterbodies for amphibian communities within the PNPG, it has several limitations. Surveys were conducted over one week during just two consecutive breeding seasons, which may not capture the full temporal dynamics and seasonal variations that could influence amphibian abundance, breeding activity, and habitat preferences. Additionally, the study was limited to waterbodies that exist within human-disturbed areas, such as villages and roads, within the northern part of the park. As a result, the findings may not be fully representative of the amphibian communities and waterbodies across the broader, more remote, and pristine areas of the national park. Lastly, another limitation is the potential for detection biases. While we conducted extensive surveys, some species, especially those with cryptic behaviors or low populations, may have been overlooked, resulting in an incomplete representation of the community's true biodiversity. Future research should aim to address these limitations by expanding the geographic and temporal coverage, incorporating a wider range of waterbodies, and incorporating more comprehensive survey techniques to provide a better understanding of amphibian diversity and conservation in PNPG.

Looking ahead, the integration of artificial waterbodies into broader conservation strategies will be essential for sustaining amphibian populations not only within PNPG but also in the face of global challenges such as climate change and habitat loss (Briggs 2010, Brand and Snodgrass 2010, Garcia-Gonzalez and Garcia-Vazquez 2011). While artificial waterbodies, such as historic water tanks and drainage channels, typically have lower species richness compared to natural ones, they often serve as the only viable breeding and refuge sites in human-altered landscapes (Brand and Snodgrass 2010, Plăiaşu et al. 2012, Buono et al. 2019, Valdez et al. 2021). As climate change intensifies, leading to more frequent and severe droughts in the Iberian Peninsula (Soares et al. 2023, Alvarez et al. 2024), artificial waterbodies will become increasingly crucial in sustaining biodiversity. Such waterbodies will be important to support not only species like *T. marmoratus*, which are highly vulnerable to climate-induced range contractions (Préau et al. 2022) but also serve as essential refuges for all species as natural habitats continue to diminish and their availability becomes more unpredictable. Indeed, our study found that while breeding events in artificial waterbodies remained stable, natural waterbodies saw a dramatic two-thirds decline during the second breeding season, underscoring the crucial role of artificial waterbodies as reliable refuges amid fluctuating conditions. This hydrological stability is particularly important for species like newts, which are more sensitive to habitat changes and climate impacts, potentially reducing the persistence of all but a few mobile and opportunistic species (Ficetola and De Bernardi 2004).

To maximize the benefits of artificial waterbodies, it's crucial to integrate their management with natural ecosystems, especially in areas like PNPG where land abandonment has led to the deterioration of these structures. Similar impacts have been observed in northern Italy, where land abandonment has negatively impacted the breeding sites of endangered amphibians (Canessa et al. 2013, Arillo et al. 2022). While fountains are more likely to be preserved for their historical and aesthetic value, they offer little support for amphibian conservation. In contrast, water tanks, which provide crucial breeding habitats for several amphibian species, receive less conservation attention due to their lower cultural significance and are more vulnerable to neglect as traditional village life and agricultural practices decline.

Effective management must not only conserve these structures but also address threats such as physical deterioration from land abandonment, chemical cleaning, and the introduction of non-native species (Chiacchio et al. 2024). Incorporating traditional and environmentally friendly land management practices can help maintain a mosaic of natural and human-altered landscapes that support optimal amphibian habitats (Briggs 2010, Plăiaşu et al. 2012). Additionally, incorporating key habitat characteristics, such as ramps in artificial habitats, has also proven effective in enhancing amphibian conservation efforts (Yu et al. 2022, Arillo et al. 2022). By integrating artificial waterbody management with natural ecosystems and holistic conservation practices, we can ensure these habitats remain critical refuges for amphibians, preserving both cultural heritage and local biodiversity amid ongoing environmental challenges.

Conclusion

This study underscores the often-overlooked yet crucial role of artificial habitats in sustaining amphibian populations within Peneda-Gerês National Park. Centuries-old water tanks and irrigation channels, remnants of traditional village life, not only offer essential refuges and breeding sites for amphibians but also reflect the region’s rich cultural heritage. As natural wetlands decrease and environmental conditions grow more unpredictable, especially with the rising frequency and intensity of droughts in the Iberian Peninsula, many of these man-made structures will become increasingly critical for maintaining local biodiversity. By integrating the management of artificial habitats with broader conservation strategies, we can better support amphibian populations, improve ecological resilience, and preserve the cultural landscapes that are intrinsic to the region's heritage.

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Appendix S1

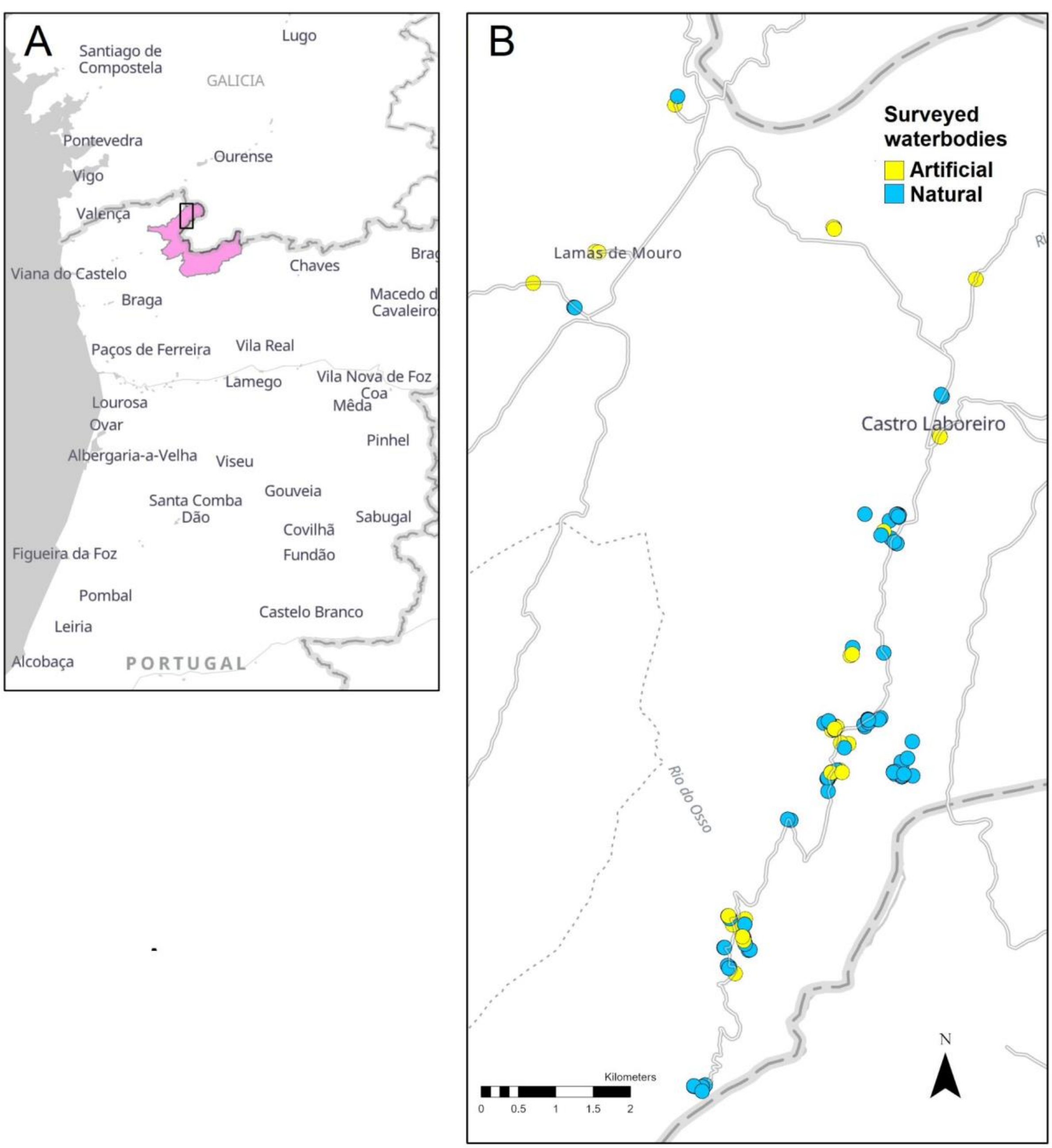

Figure S1. (A) Location of Peneda-Gerês National Park in Portugal (highlighted in pink). (B) Surveyed artificial (yellow) and natural (blue) waterbodies within the park.

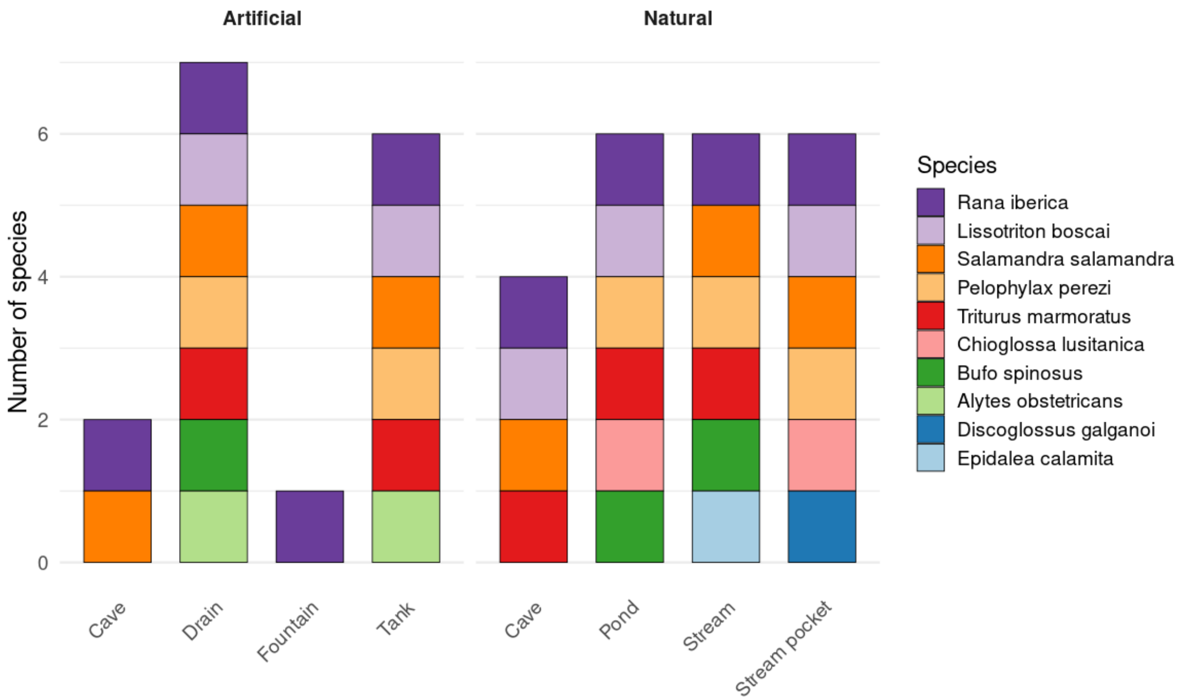

Figure S2. Stacked bar plot depicting amphibian species richness in artificial and natural waterbody types. Each bar represents the number of species for each type of waterbody, with colors indicating the different species observed within that specific waterbody type. Species are ordered by the most commonly found.